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A Collection of Flow Visualization Techniques Used in the Aerodynamic Research Branch

Staff, Aerodynamic Research Branch

December 1984

National Aeronautics and
Space Administration

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Space Administration

Ames Research Center
Moffett Field, California 94035

N85-15125 #

CONTENTS

INTRODUCTION

The Aerodynamic Research Branch is responsible for both theoretical and experimental research on steady and unsteady aerodynamic flows. Many of our research programs are concerned with complex flow fields that involve separations, vortex interactions, and transonic flow effects. To fully appreciate the spacial relationships in such flows, it is imperative that the most up-to-date flow visualization techniques be used to obtain a global picture of the flow phenomena before detailed quantitative studies are undertaken. A wide variety of methods are used to visualize fluid flow and a sampling of these methods is presented in the enclosed informal collection.

It must be stressed that the visualization technique is but a means to an end, this being a thorough quantitative analysis and subsequent physical understanding of these flow fields.

Sanford Davis
Chief, Aerodynamic Research Branch

DYE INJECTION TECHNIQUE FOR WATER FLOWS

Dyes are often used as tracers to visualize flow patterns in water. They can be injected into the flow by several different methods. One method injects dye filaments into the region of interest to visualize streak lines. Dye filaments can also be injected locally from the model to visualize flow phenomena near the model. For two-dimensional models such as a wing, sheets of dye can be injected from strategically placed slots.

Experimental Arrangement

A NACA 0012 airfoil is installed in the Ames-Dryden Water Tunnel. An upstream vortex generator (finite span wing at a small incidence angle) produces a free longitudinal vortex (red dye) that interacts with the wing boundary layer (green dye). The chord Reynolds number is approximately 50,000. The resulting vortex-wing interaction is shown in figures 1 and 2.

Experimenters

T. T. Lim; R. Mehta

Date of Experiment

July 1983

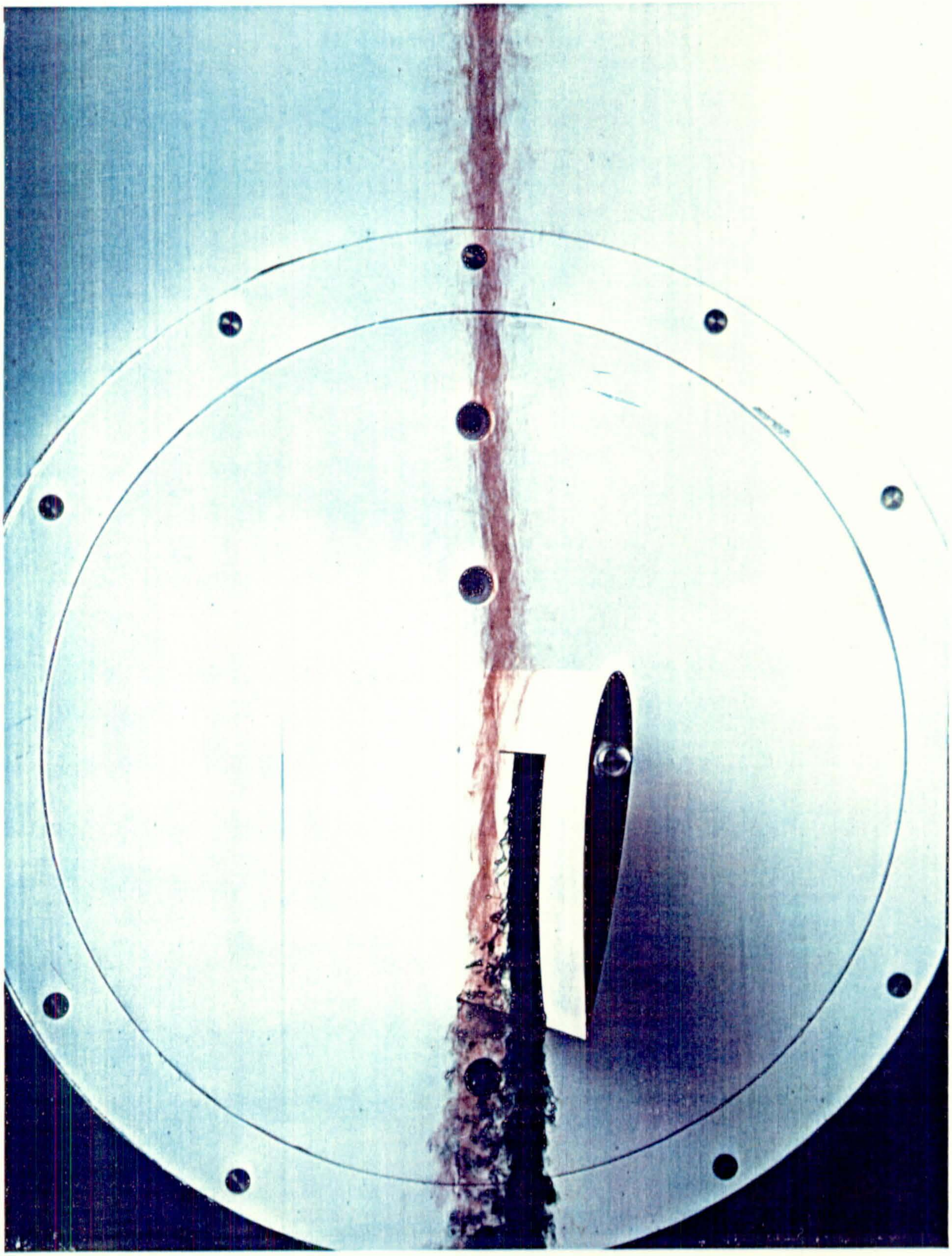


Figure 1.- A side view of vortex/wing interaction, angle of attack (α) = -5°.

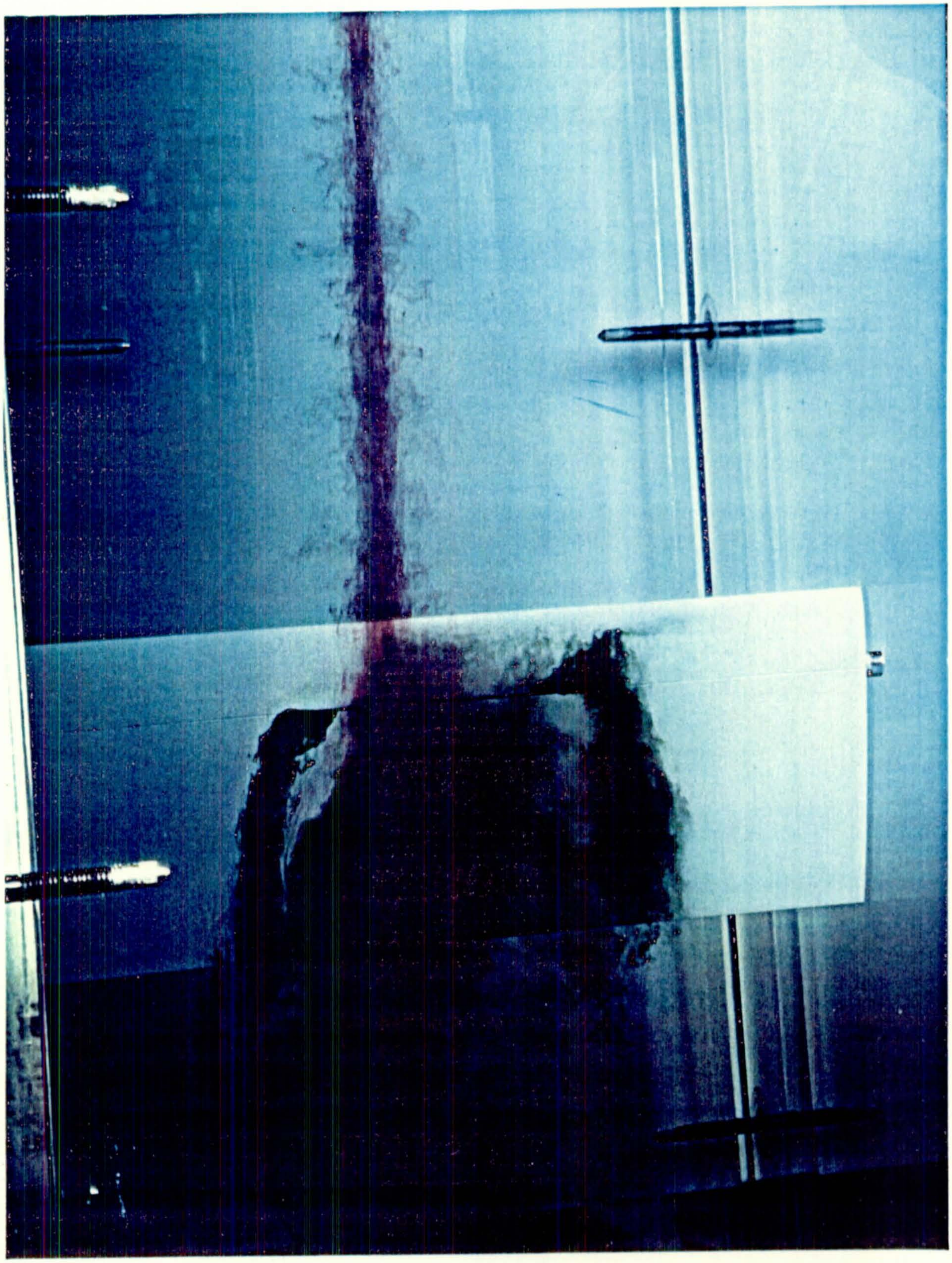


Figure 2.- A plan view of the interaction showing asymmetric separation, $\alpha = +10°$.

HYDROGEN BUBBLE TECHNIQUE

Hydrogen bubbles are used as tracers to visualize flow patterns in a water tunnel. The hydrogen bubbles are generated by electrolysis with small wires acting as cathodes. Bubbles that are formed on the wire are carried in the flow, tracing out streak lines. In steady flows, streak lines are identified with streamline patterns. To visualize the local flow near the model, such as separated flow regions, wires can be placed on the model.

Experimental Arrangement

The classical problem of the flow about a circular cylinder was studied in the NASA Ames-Army Water Tunnel. Flow visualization pictures at two widely separated Reynolds numbers are shown in figures 3 and 4. This technique was also applied to the vortex-wing interaction and is presented in figures 5 and 6.

Experimenters

U.S. Army Water Tunnel: D. Almosnino; K. McAlister
Ames-Dryden Water Tunnel: T. T. Lim; R. Mehta

Dates of Experiments

U.S. Army Water Tunnel: January 1983
Ames-Dryden Water Tunnel: July 1983

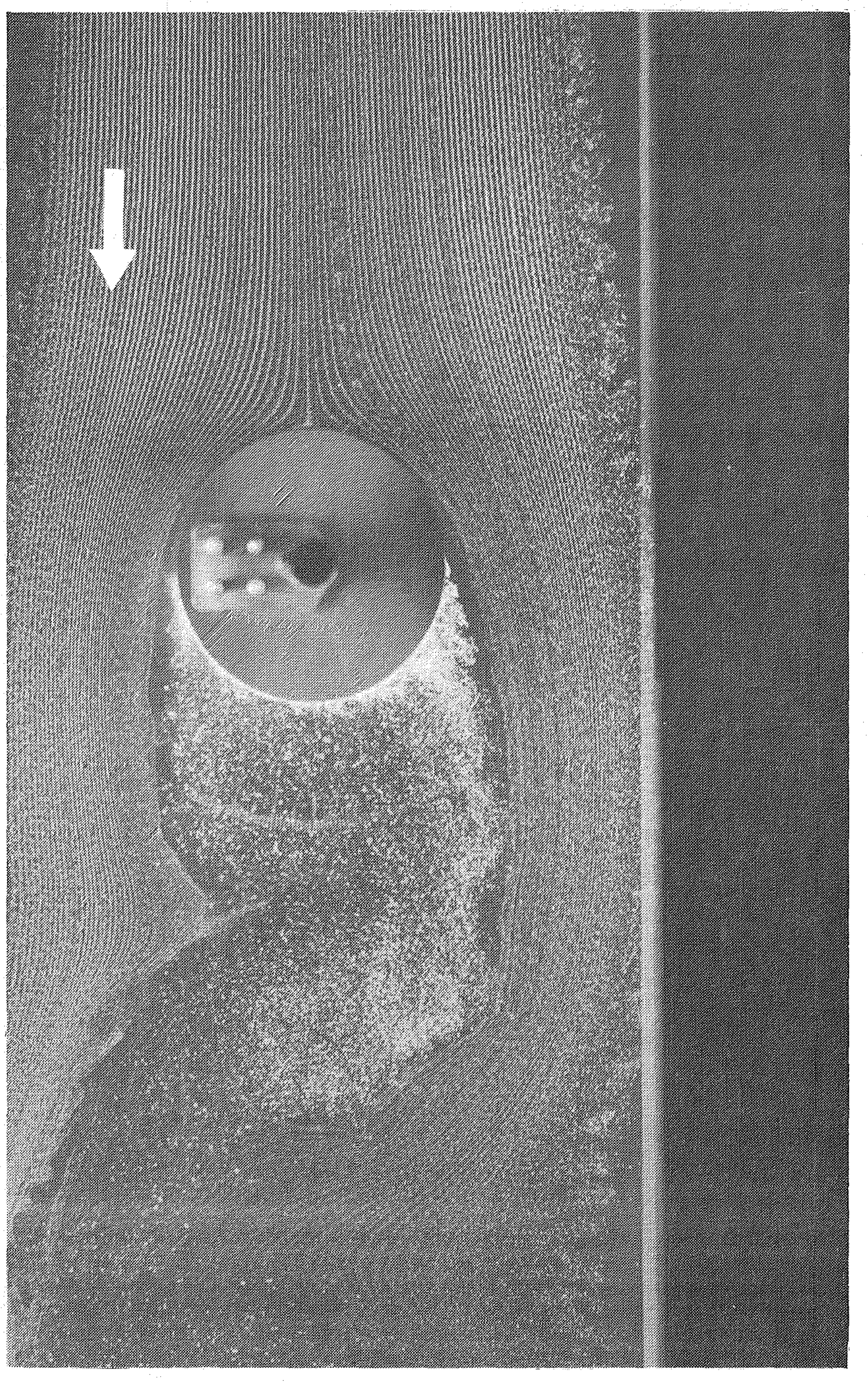


Figure 3.- Cylinder in water with hydrogen bubbles, Reynolds number = 35,000.

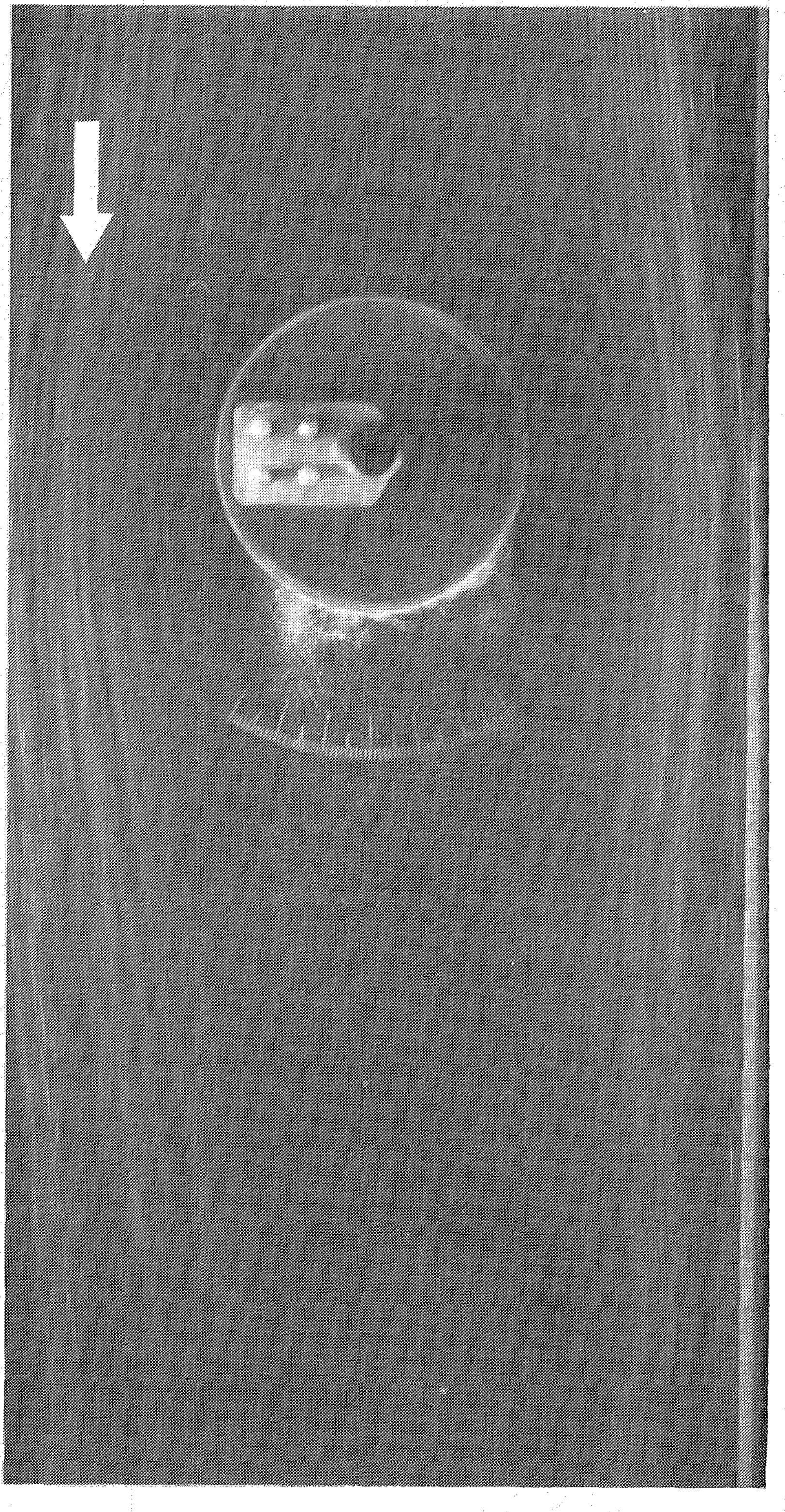


Figure 4.- Cylinder in water with hydrogen bubbles, Reynolds number = 300,000.

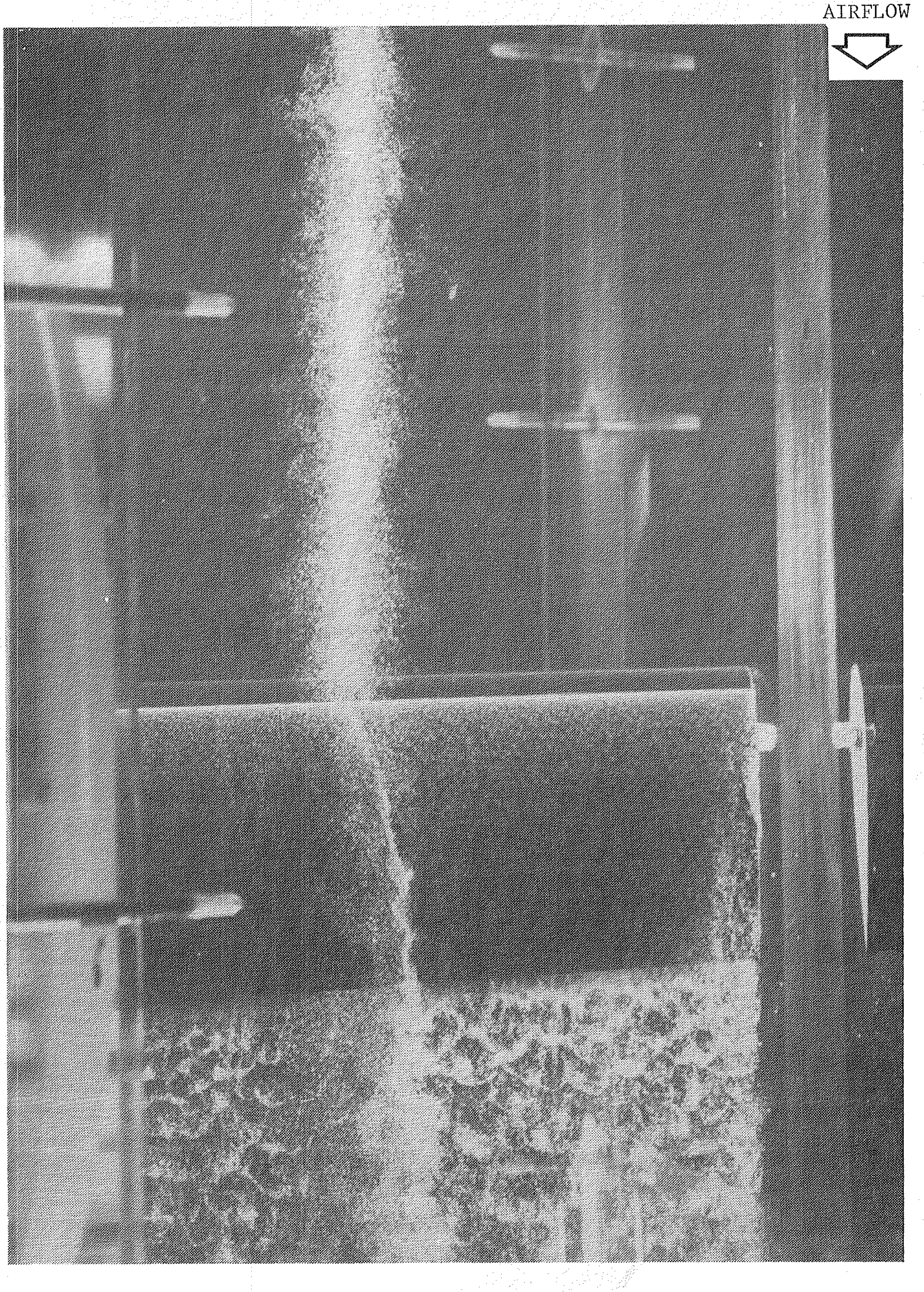


Figure 5.- A plan view of vortex interacting with an airfoil, Re_c = 37,000, α = 0°.

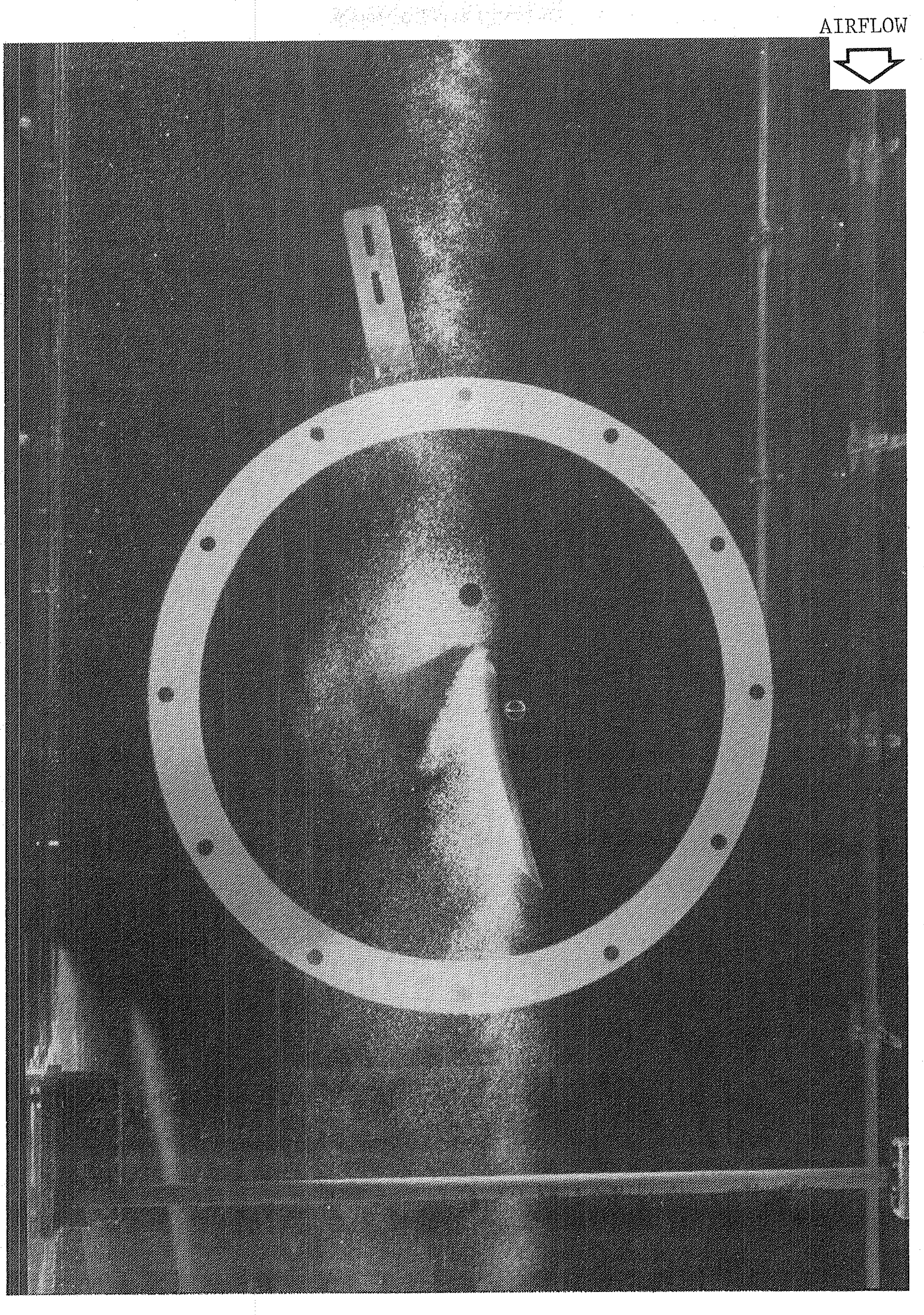


Figure 6.- A side view of vortex interacting with a stalled airfoil, Re_c = 37,000, α = +12.5°.

SMOKE INJECTION FOR LOW-SPEED AIRFLOW

Several smoke-injection techniques may be used for flow visualization. One involves injecting a single filament of smoke ahead of the model. When the filament hits the model stagnation point, the smoke spreads over the model and enables visualization of the flow near the model surface. As an extension of this method, multiple smoke filaments may also be used. Another option is to inject smoke in filaments or sheets from the model itself. A bright light shining on the smoke makes the smoke pattern visible. Recently, laser light in the form of a sheet or a large beam has been used. This allows visualization of the local flow near the model, such as flow reversal and other complex patterns.

Experimental Arrangement

A small wing located in the nozzle of a 35- by 15-cm shear layer wind tunnel generates a longitudinal vortex that interacts with a free-shear layer. A sheet of laser light is used to highlight the interaction in the cross-flow plane. This visualization technique is illustrated in figures 7 and 8.

Experimenter

R. Mehta

Date of Experiment

February 1983

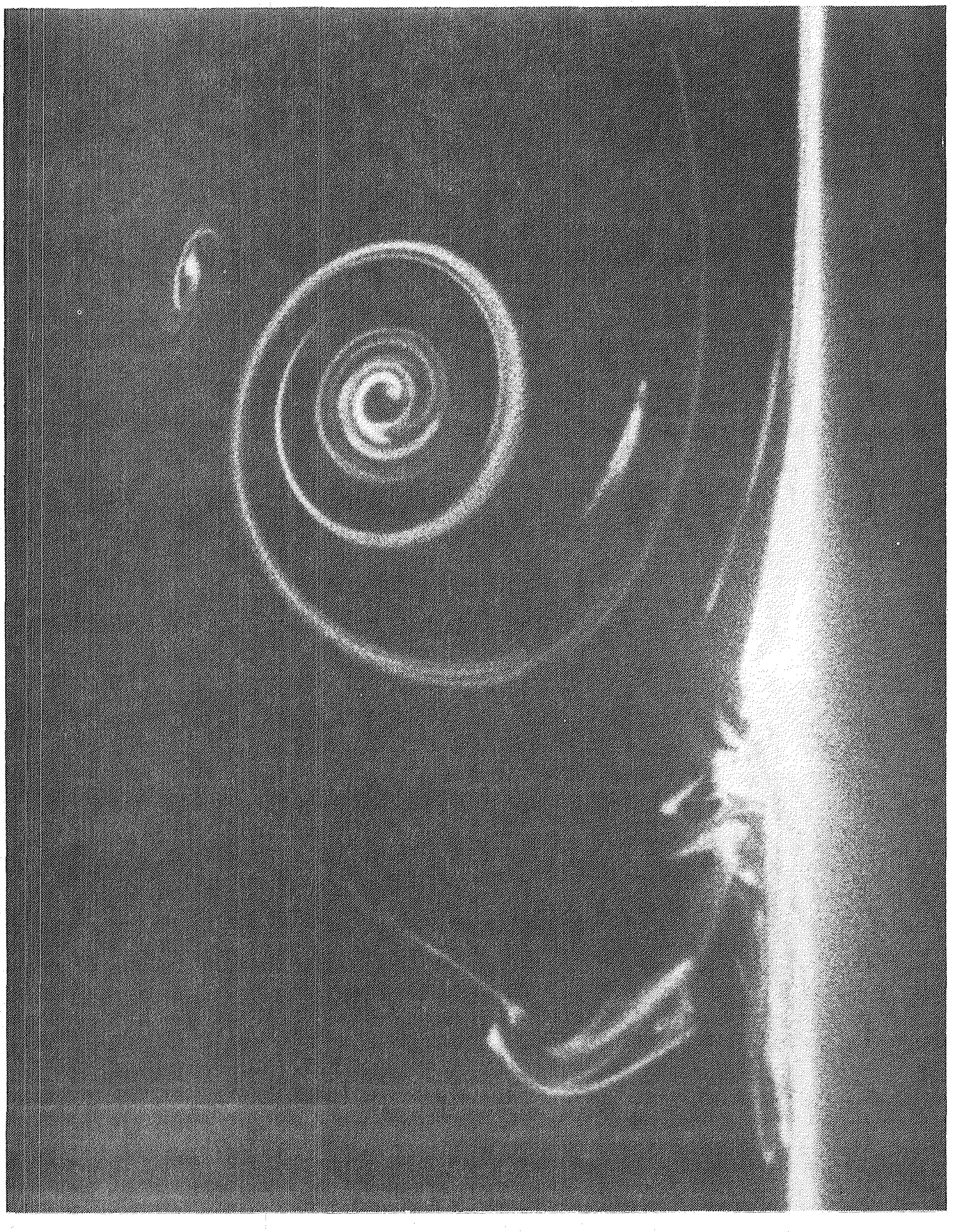


Figure 7.- A cross section through the generated vortex before the interaction occurs.

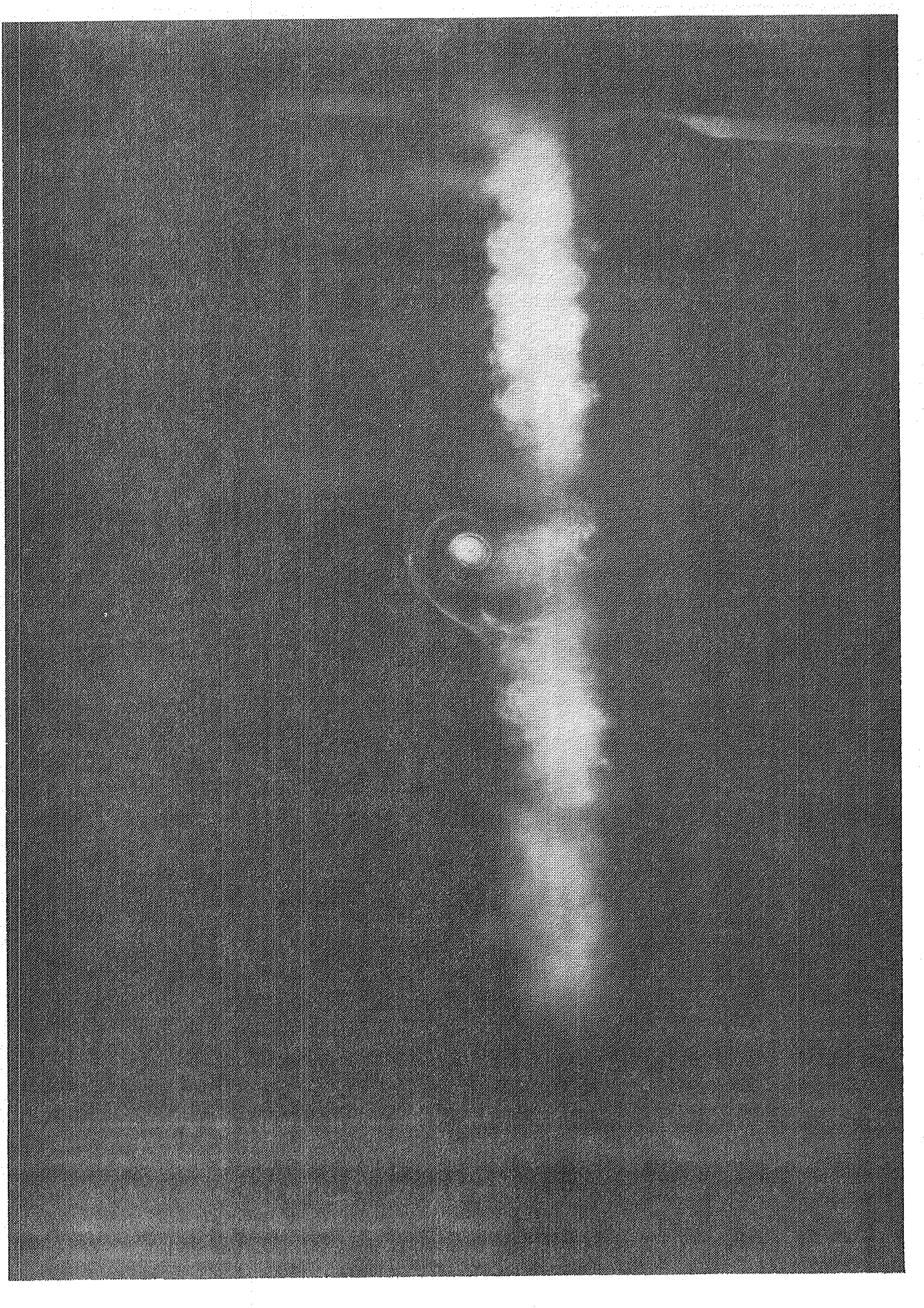


Figure 8.- Vortex interacting with a free-shear layer.

STROBOSCOPIC SCHLIEREN SYSTEM

Stroboscopic flow visualization is used to analyze unsteady flows by using a pulsed light source to illuminate the flow at prescribed instants of time. The overall effect created is that of stopped motion. If the phase relationship between the source and flow field is slowly varied, a slow-motion picture of the flow field in real time is obtained. The schlieren effect is sensitive to density gradients that may be enhanced in low-speed flows by using heated wires embedded in the test models.

Experimental Arrangement

The near wake behind a pitching airfoil (NACA 64A006, c = 15 cm) is examined in the NASA Ames 25- by 35-cm Indraft Wind Tunnel. A thin Ni Cr wire was embedded in the airfoil near the trailing edge. Figure 9 shows the wake pattern at 45° phase increments at a relatively high, reduced frequency of $k \sim 8$. (Note that frames 1 and 9, at phases 0 and 2π, respectively were photographed independently.) At this frequency, the maximum trailing-edge velocity was about 40% of the free stream velocity and the wake is highly distorted. The presence of locked-in instability waves on the wake is also shown in this sequence. (Further details may be found in the article "Visualization of Quasiperiodic Flows," AIAA J., 17, 1979, pp. 1164-1169.)

Experimenters

R. Kadlec; S. Davis

Date of Experiment

August 1975

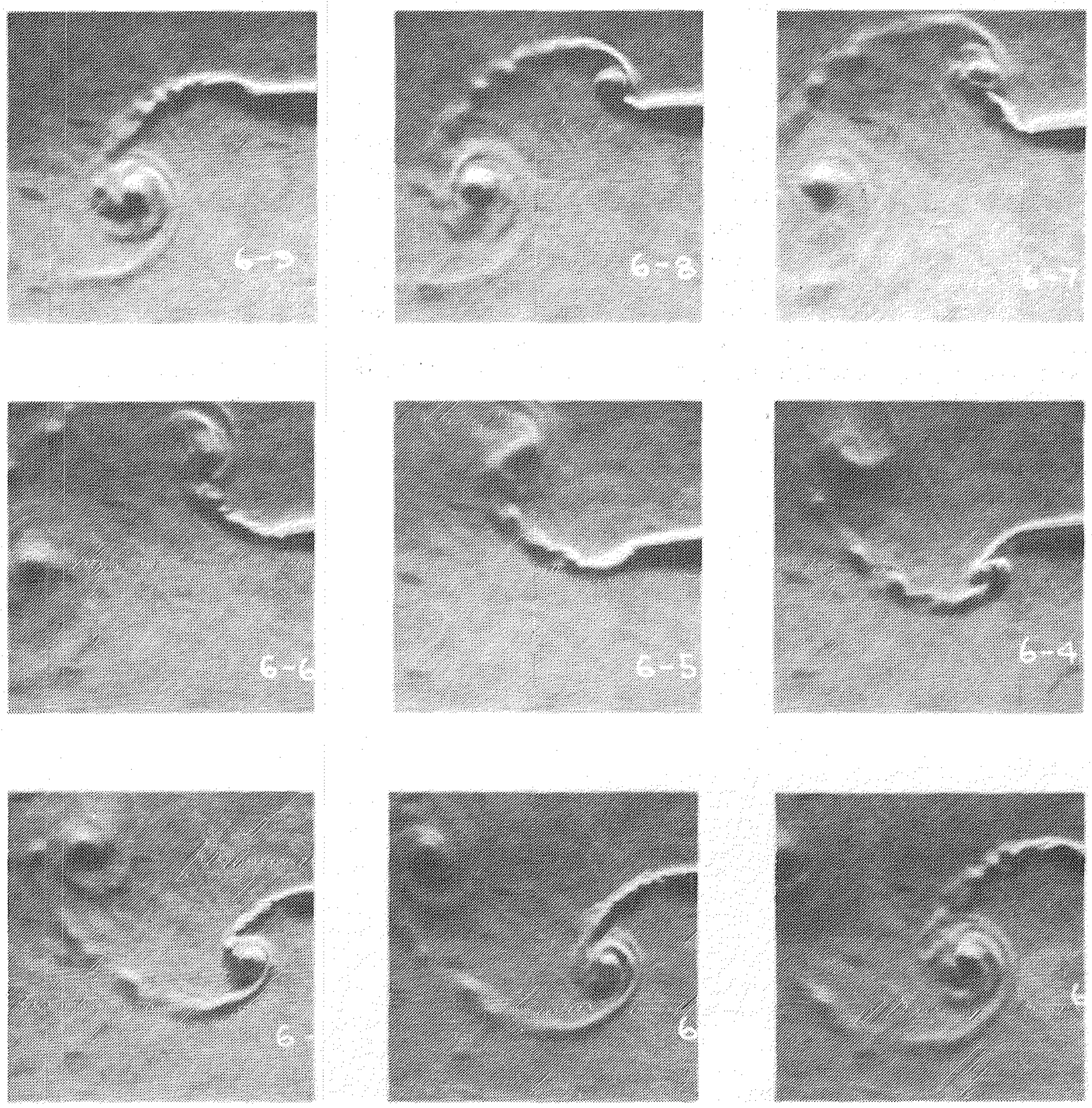


Figure 9.- Stroboscopic schlieren photographs showing wake pattern from an oscillating airfoil at phase increments of $\pi/4$.

COLOR STROBOSCOPIC SCHLIEREN SYSTEM

An existing stroboscopic schlieren system developed by Kadlec and Davis was modified by using a strobe light and appropriate optical components. The original black and white system was modified to a color schlieren system by introducing an array of color transparencies instead of the usual slit arrangement. The resulting color pattern on the schlieren picture can be resolved into bars of constant density.

Experimental Arrangement

An airfoil model (c = 7.6 cm) (fig. 10) is oscillating in the Ames 25- by 11-cm Indraft Wind Tunnel at a frequency of 20 Hz. The free-stream Mach number is 0.75.

Experimenters

S. Bodapati; G. Hadjidakis

Date of Experiment

December 1982

Figure 10.- Composite schlieren photograph showing color-coded bars of constant density at various phase positions during an oscillation cycle.

SURFACE FLOW VISUALIZATION TECHNIQUES

The oil-flow technique uses an oil- and powdered-pigment mixture painted on the model to create streak patterns that indicate the surface flow field. The sublimation technique uses a solution of a suitable subliming solid in a highly volatile liquid sprayed on the model to locate boundary-layer transition by the different rates of sublimation in laminar and turbulent flows.

Experimental Arrangement

Figure 11 shows the surface oil-flow patterns on the upper surface of a wing model tested at transonic speed. The oil streaks show the direction of the air flow over the surface and the occurrence of local flow separation.

Figure 12 shows surface oil-flow and sublimination patterns at low speed in side views of a pointed body of revolution. A heavy flow-separation line occurs in the oil flow and a boundary-layer transition line occurs in the sublimation along the side.

Figure 13 shows surface oil-flow patterns on a swept bump research model at transonic speeds. The oil streaks indicate highly three-dimensional flow terminated by a flow-separation line.

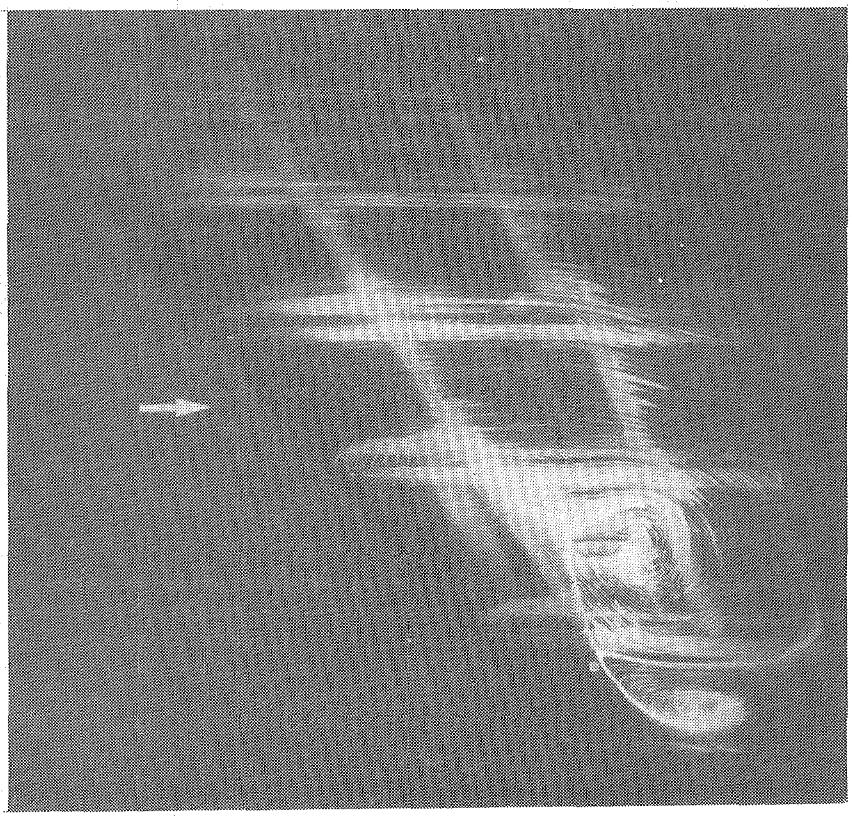
Figure 14 shows a surface oil-flow separation pattern on an axisymmetric bump research model at transonic speeds. A vortex was generated upstream and passed close to the surface of the bump, causing the "footprints" of vortices in the flow separation pattern.

Experimenters

Wing model: E. Keener
Body of revolution: E. Keener
Swept bump: O. Ozcan, D. Johnson
Vortex/bump: R. Mehta

Dates of Experiments

Wing model: August 1982
Body of revolution: June 1976
Swept bump: June 1983
Vortex/bump: September 1983



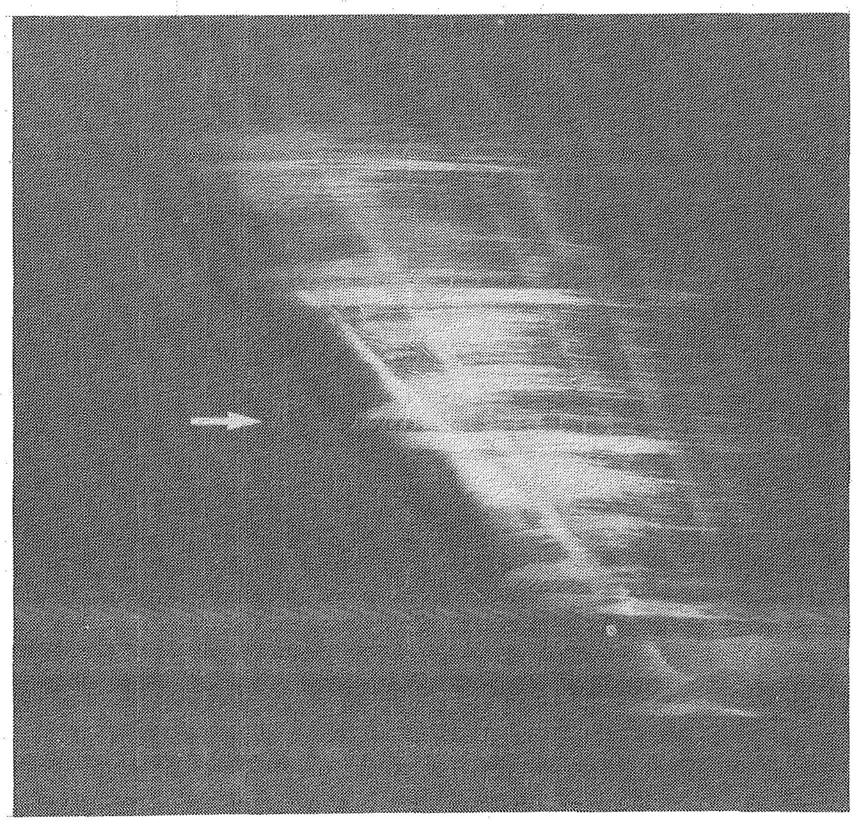


Figure 11.- Surface oil-flow features on a wing model tested in the NASA Ames 6- by 6-Foot Supersonic Wind Tunnel. Upper: separated; lower: attached.

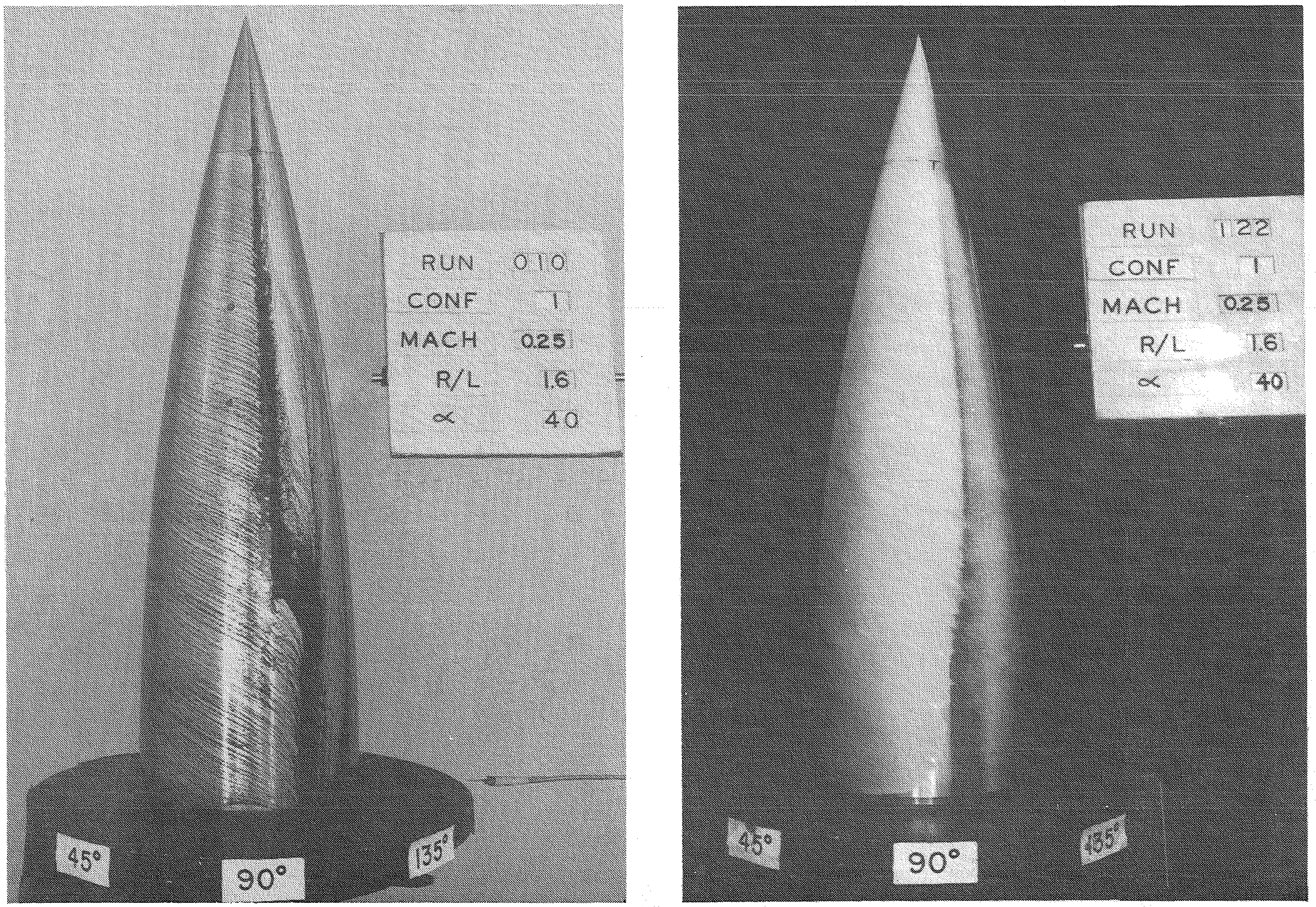


Figure 12.- Oil-flow and sublimation patterns on a body of revolution in the NASA Ames 12-Foot Pressure Wind Tunnel; left-side views. Left: Oil flow; right: sublimation.

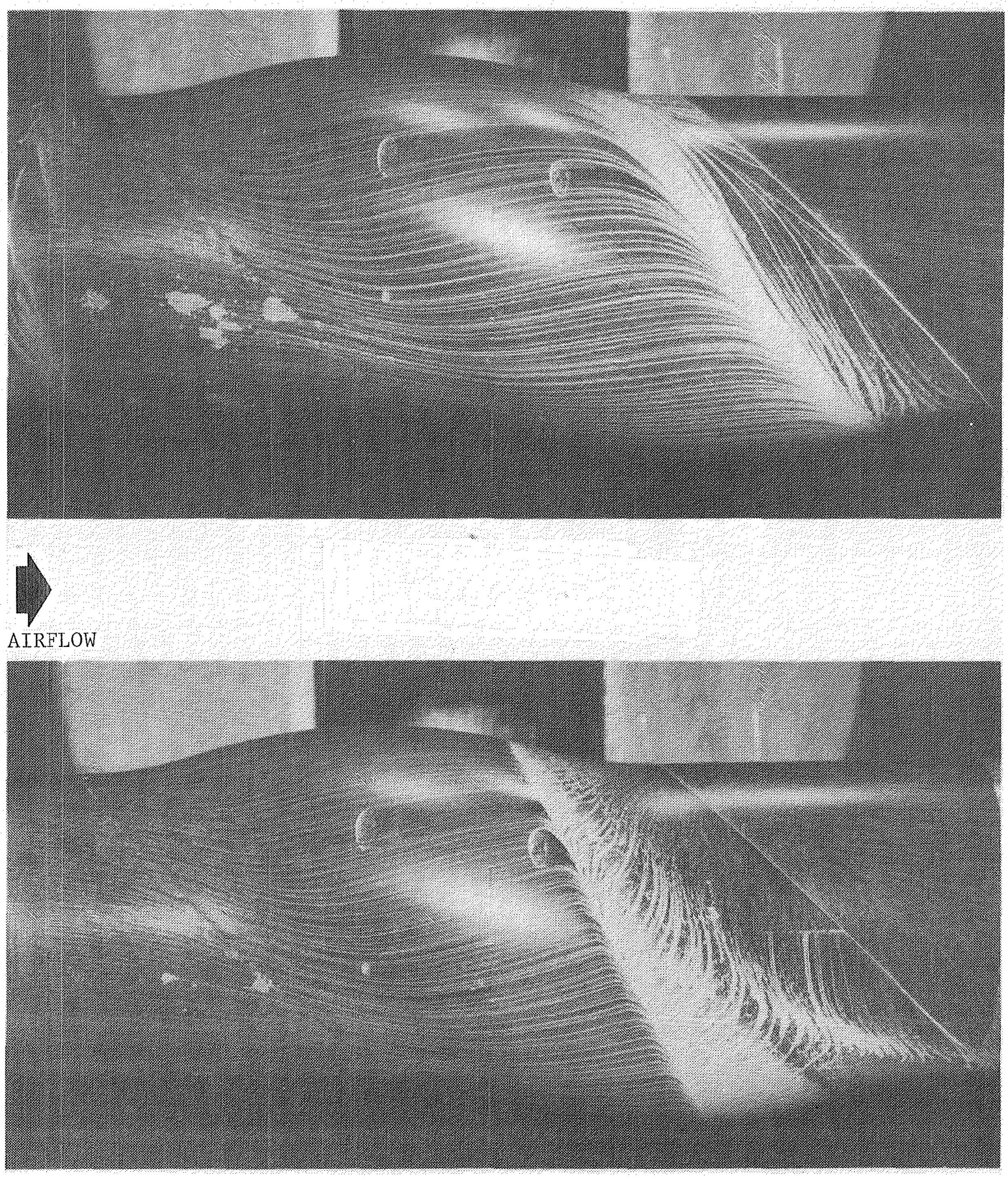


Figure 13.- Surface oil-flow features on a swept bump research model in the NASA Ames 6- by 6-Foot Supersonic Wind Tunnel. Above, M = 0.7; below, M = 0.925.

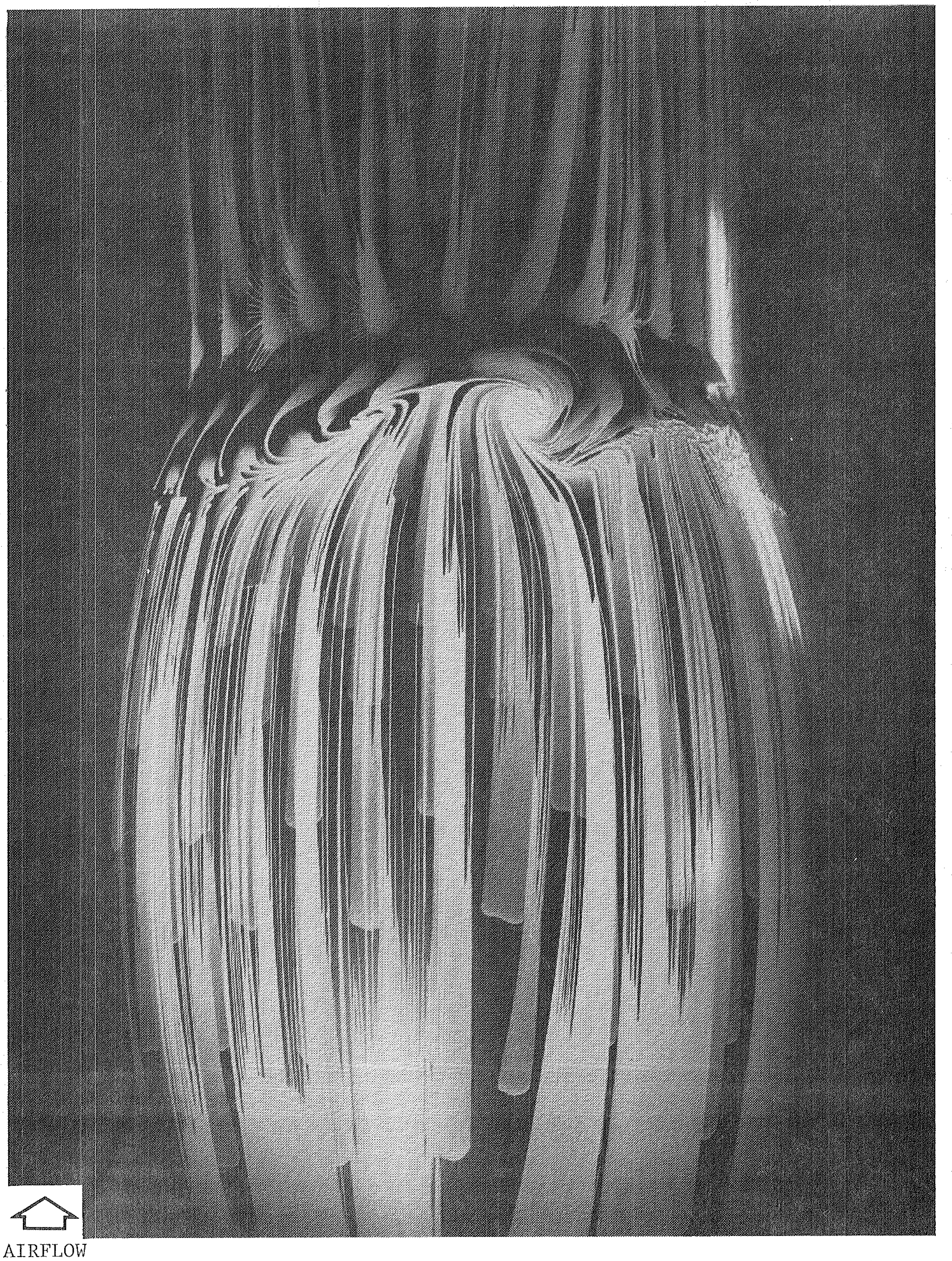


Figure 14.- Effect of vortex on a separated boundary layer, M = 0.8.

LASER HOLOGRAPHIC INTERFEROMETRY TECHNIQUE

Mach-Zehnder interferometry has been used for many years to study flows in wind tunnels. More recently, holographic interferometry has become an accepted method. The pulsed lasers allow interferometry to be operated in the high-vibration wind tunnel environment where holography allows cancellation of phase errors caused by low-quality windows. The technique determines the distribution of change of refraction index throughout the flow field. From the refractive index, the density field can be determined. Other flow parameters such as Mach number, velocity, and pressure can be calculated by assuming isentropic flows. Shock waves, boundary layers, and wakes can be readily seen by this technique.

Experimental Arrangement

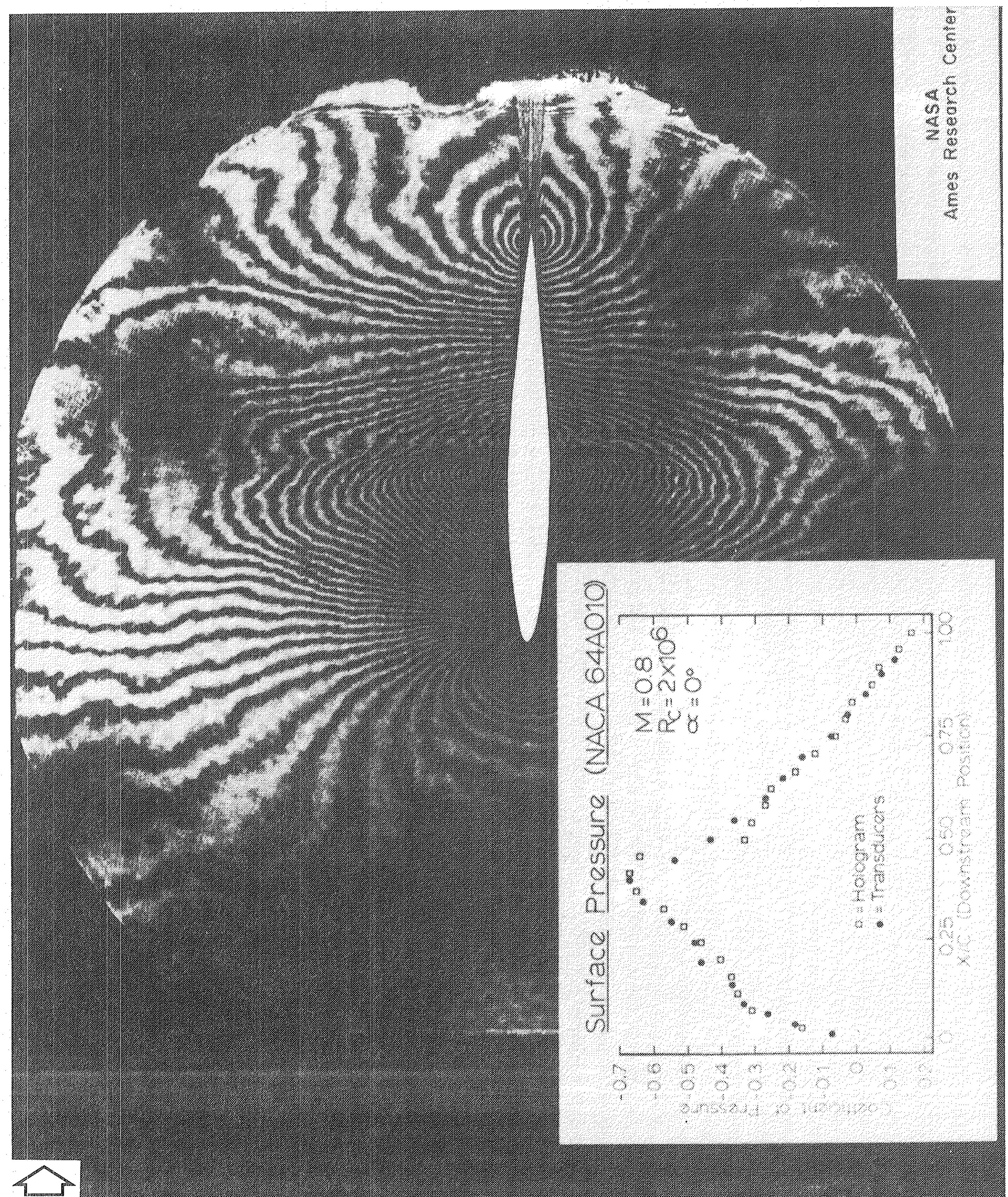
A series of two-dimensional airfoils have been studied by holographic interferometry to measure surface pressures, density fields, wakes, and complex flow fields. Figure 15 shows an interferogram of a NACA 64A010 airfoil in which surface pressure distributions were obtained by holographic interferometry. The instantaneous density field and the wake of a NACA 0012 airfoil undergoing dynamic stall in the Ames 2- by 2-Foot Transonic Wind Tunnel is shown in figure 16. Figures 17 and 18 show the complex flow fields on a circulation control airfoil. The detailed interaction of the jet and the flow near the trailing edge of the airfoil can be seen in figure 18. The investigation of the instantaneous density fields on an airfoil with an oscillating flap are shown in figure 19. This technique has also been used for investigation of three-dimensional flows using tomography as shown in figure 20.

Experimenters

W. Bachalo, D. Johnson, G. Lee, D. Buell, N. Wood, R. Perry

Dates of Experiments

1978-1983



AIRFLOW

Figure 15.- Analysis of density fields to determine surface pressures in a two-dimensional airfoil test in the NASA Ames 2- by 2-Foot Transonic Wind Tunnel.

Figure 16.- Investigation of instantaneous density field on an airfoil undergoing dynamic stall in the NASA Ames 2- by 2-Foot Transonic Wind Tunnel.

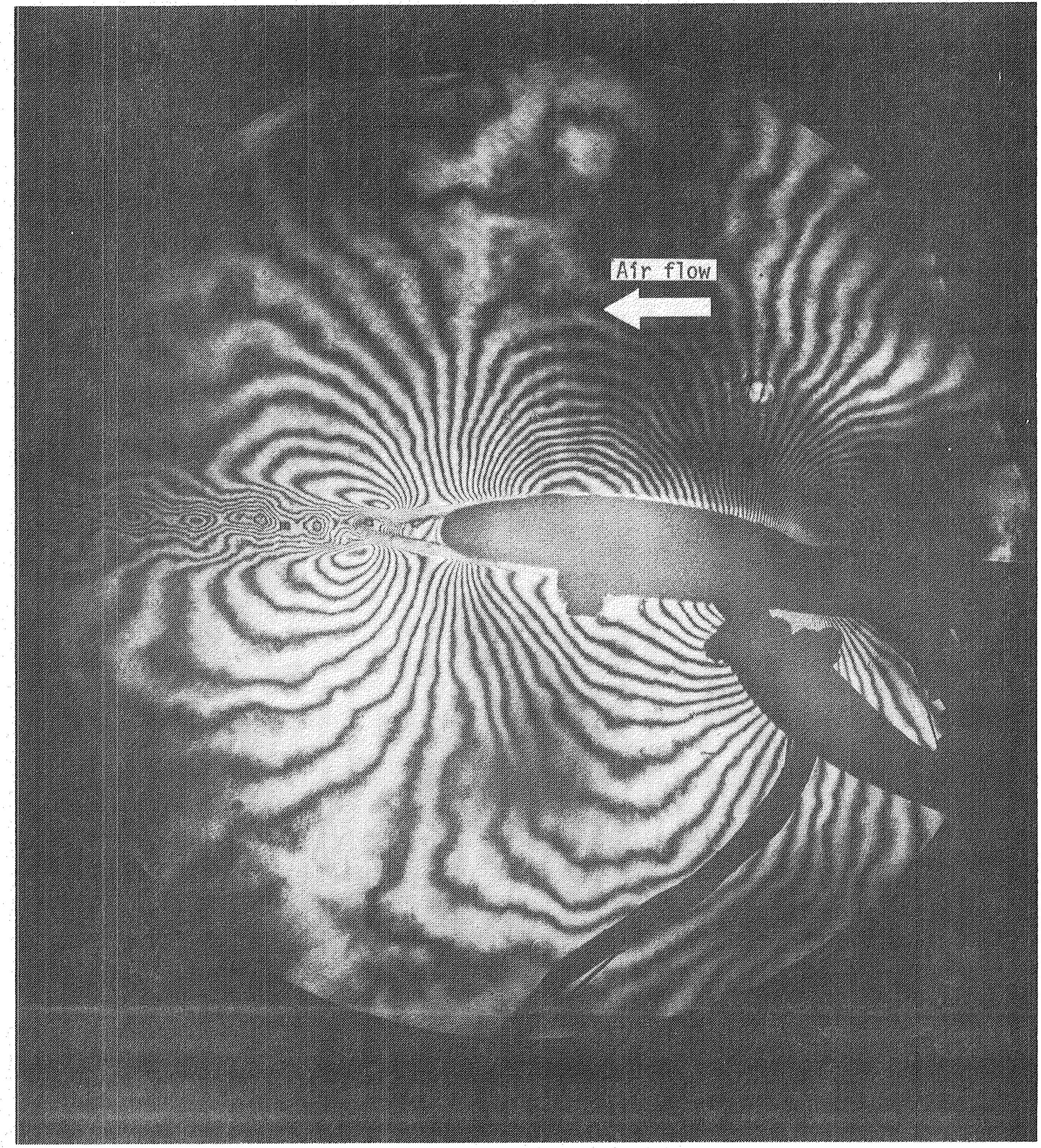


Figure 17.- Circulation control airfoil. Mach = 0.50, $C_\mu = 0$.

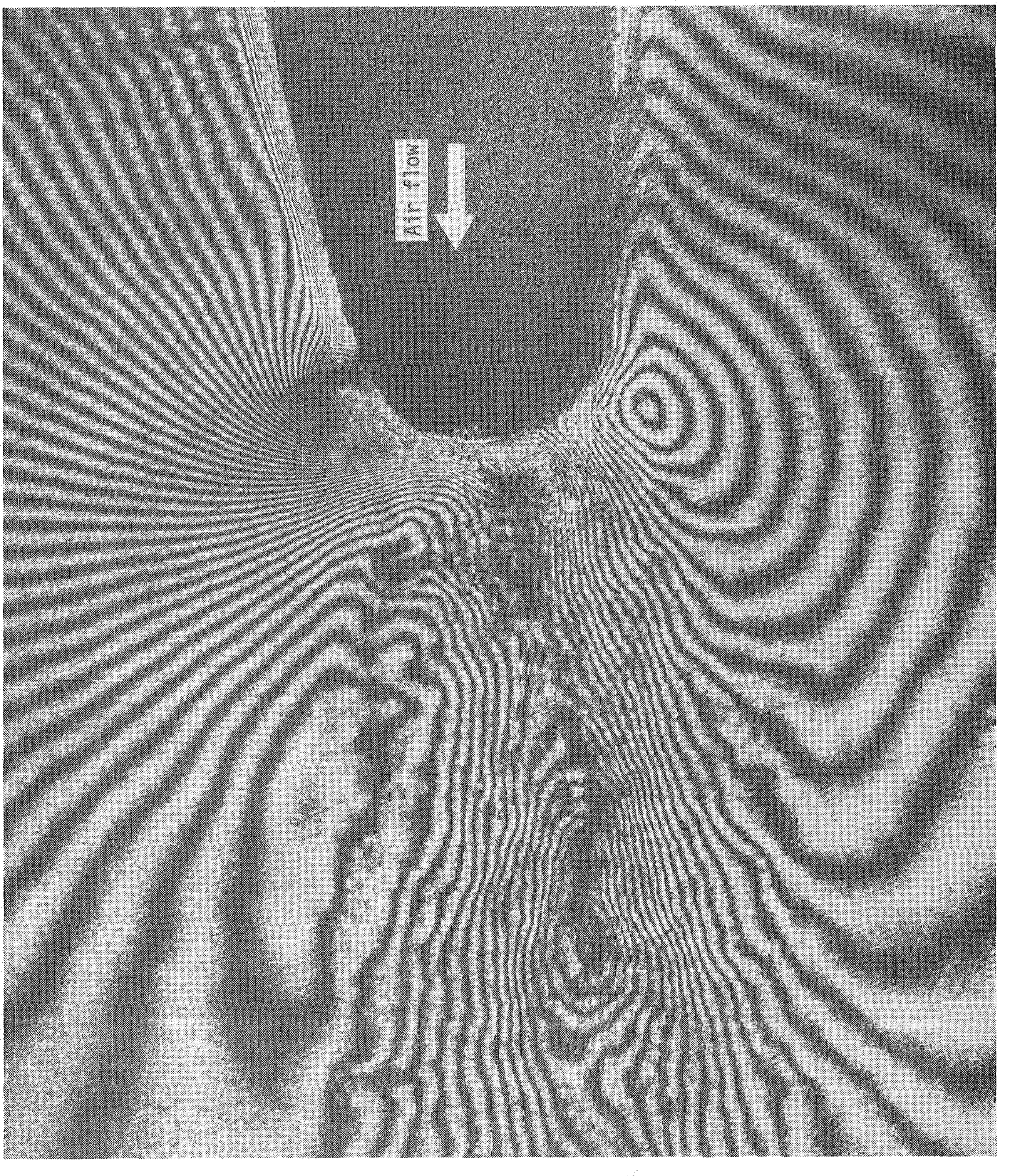


Figure 18.- Trailing edge of circulation control airfoil. Mach = 0.50, C_μ = 0.018.

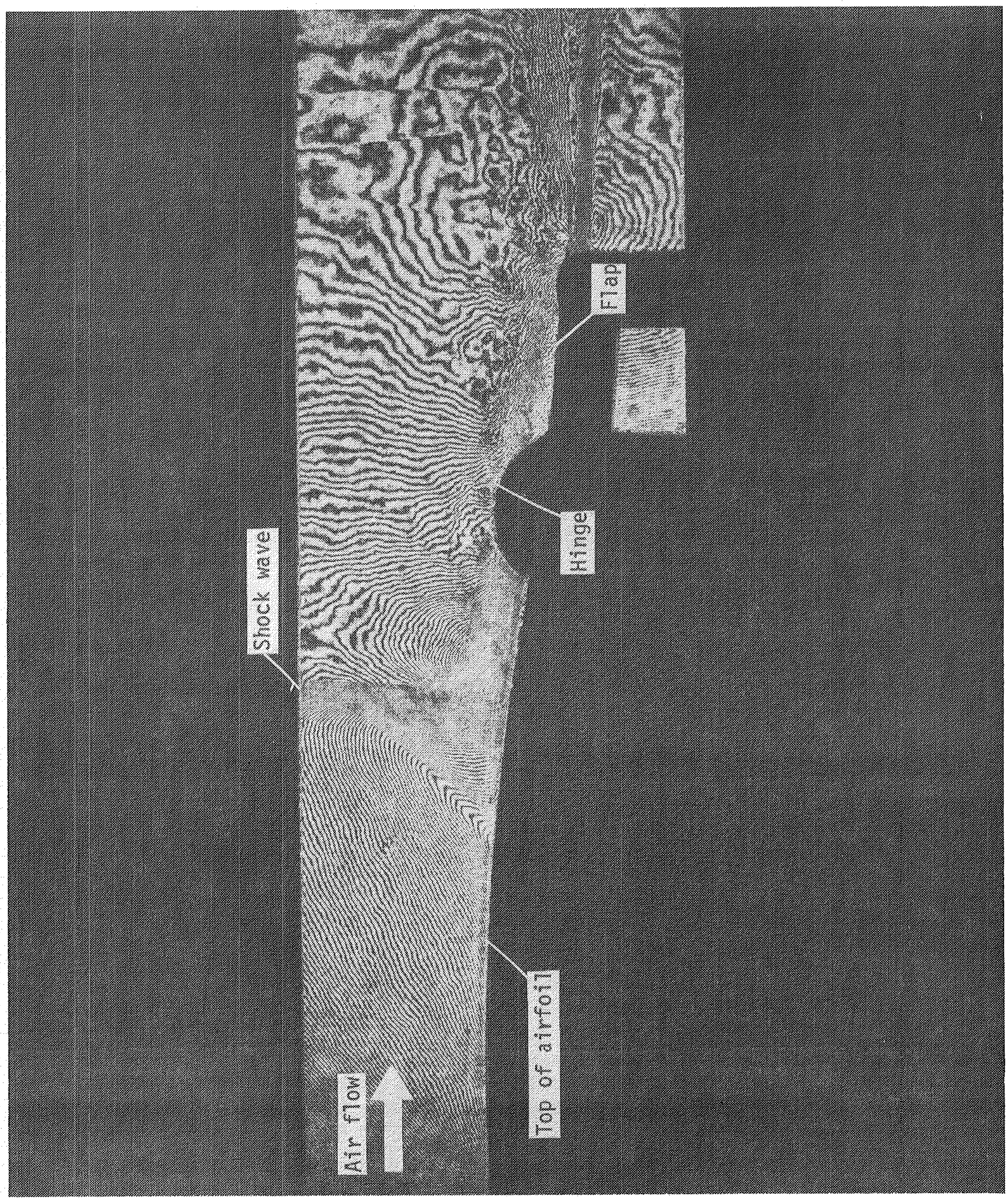


Figure 19.- Oscillating flap at Mach = 0.80.

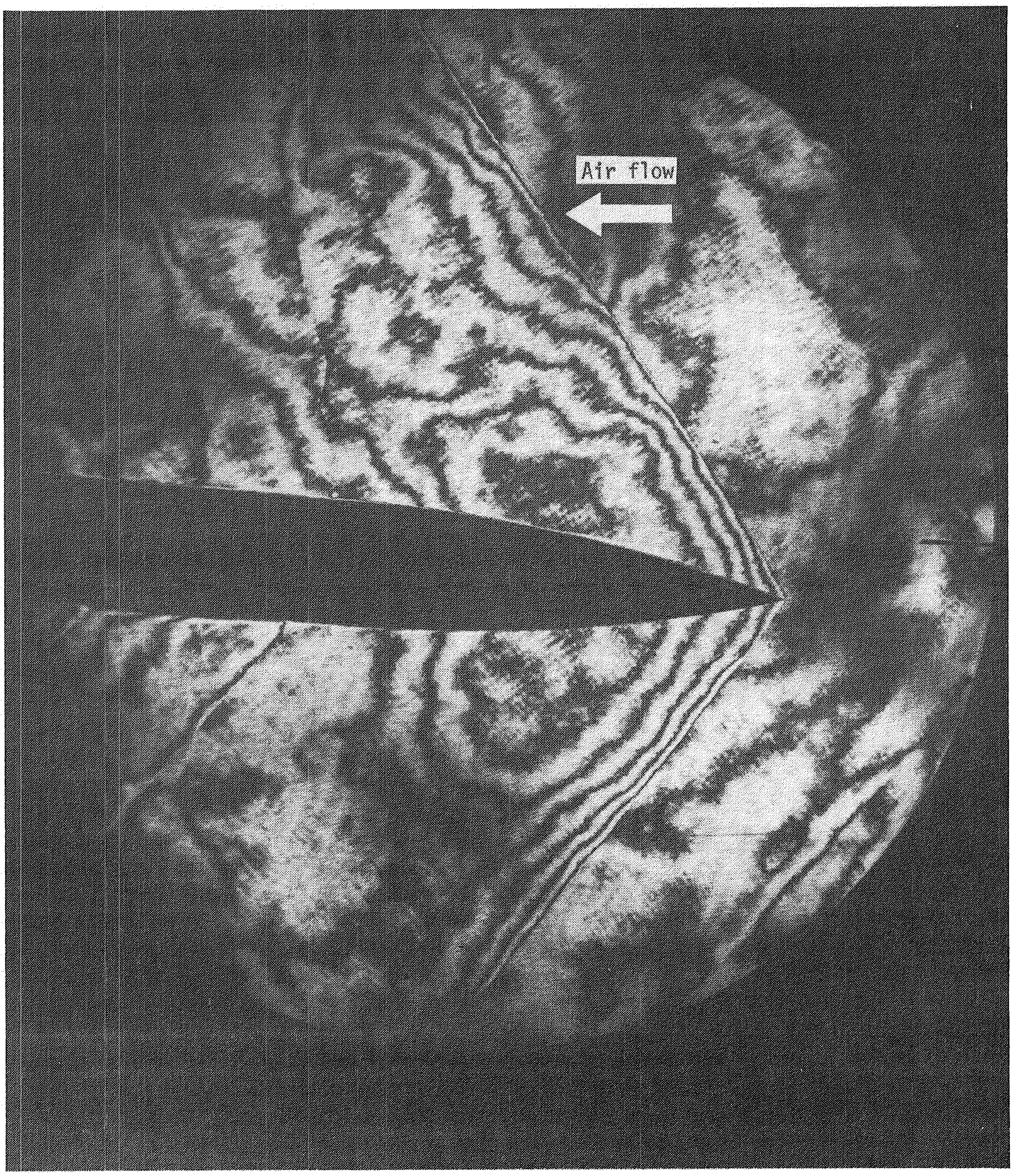


Figure 20.- Interferogram of tangent-ogive at Mach = 1.25.

LASER-INDUCED FLUORESCENCE

Laser-induced fluorescence is a hydrodynamic-flow-visualization method that uses dyes which fluoresce when excited by a laser light of a given wavelength. In practice, a laser light beam can be confined to a particular plane of the flow field through the use of optical element combinations. This sheet of laser light excites the dyes present in the flow and provides a detailed interior view of a slice of the flow field. Multicolor tagging of the flow is possible by using dyes that fluoresce different colors for the same light wavelength of excitation.

Experimental Arrangement

Figures 21 and 22 show two experiments conducted in the Ames-Army Water Channel: a vortex-wing interaction and a circular cylinder wake. The experimental arrangement for the vortex-wing interaction is similar to that described previously in "Dye Injection Technique for Water Flows." Note that figure 21 shows a cross-flow-plane view of the interaction between a streamwise vortex and a two-dimensional wing. The laser sheet is vertically aligned parallel to the wing's trailing edge. The vortex is green, the rotation being counterclockwise, and the wing's upper-surface boundary-layer material is yellow. The two-dimensional wing is at an angle of attack of 0° and has a NACA 0012 profile. The wing Reynolds number, based on chord, is 4500.

Experimenter

B. G. McLachlan

Date of Experiment

January 1984

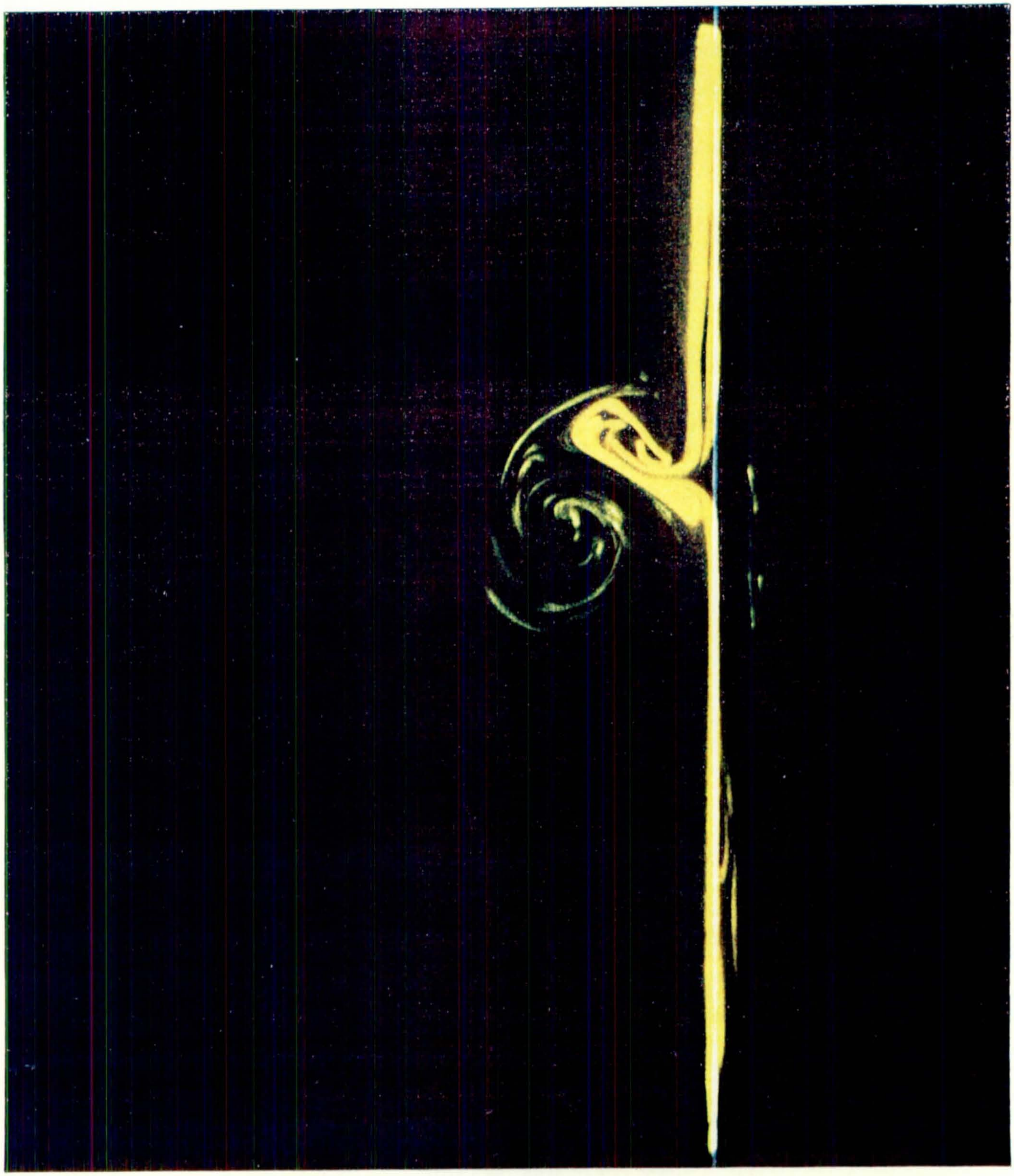


Figure 21.- Cross-flow plane view of vortex wing interaction. Re = 4500.

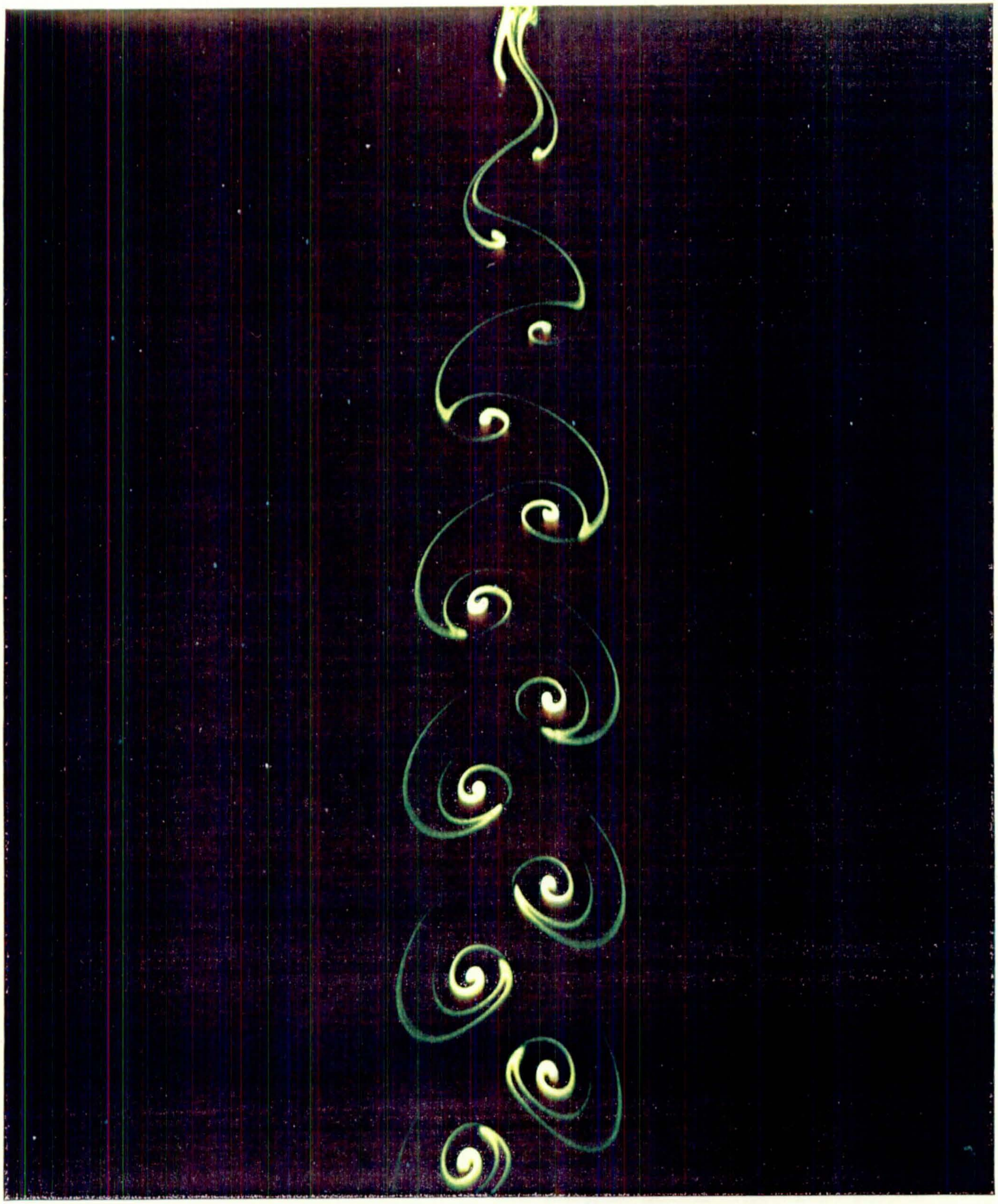


Figure 22.- Karman vortex street behind a circular cylinder. Re = 58.

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Washington, D.C. 20546

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16 Abstract

The Aerodynamic Research Branch is responsible for both theoretical and experimental research on steady and unsteady aerodynamic flows. Many of our research programs are concerned with complex flow fields that involve separations, vortex interactions, and transonic flow effects. To fully appreciate the spacial relationships in such flows, it is imperative that the most up-to-date flow visualization techniques be used to obtain a global picture of the flow phenomena before detailed quantitative studies are undertaken. A wide variety of methods are used to visualize fluid flow and a sampling of these methods is presented in the enclosed informal collection.

It must be stressed that the visualization technique is but a means to an end, this being a thorough quantitative analysis and subsequent physical understanding of these flow fields.

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Water tunnels
Holography
Separated flows
Vortex flows

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